SITE-SPECIFIC ASSESSMENT OF

THE PROPOSED URANIUM MINING AND MILLING PROJECT

AT COLES HILL, PITTSYLVANIA COUNTY, VA

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Executive Summary[1]

This paper focuses on technical issues. However, it is important to remember that the available site data were produced by the companies with a financial interest in ensuring that the existing uranium mining ban is lifted. All of the publicly-available technical data and information for these proposed operations were collected by the mining companies or by consultants / contractors paid by these companies. Most of the publicly-available opinions on future impacts that might result from such operations also come from the companies or their paid contractors.

The uranium mining industry's track record in this country and throughout the world demonstrates that the industry's predictions in regard to potential impacts on water resources and public health, as well as promised socioeconomic benefits are overly optimistic. The most powerful influences in any decision on uranium mining and processing are likely to be financial and political. Thus, it is imperative that the public evaluate the long-term, "big picture" because the actual impacts will be paid for by numerous future generations.

This paper offers recommendations to decision-makers and communities on measures that should be taken to protect the public welfare prior to the commencement of the project. Specifically, the paper discusses the importance of the baseline data collection and sufficient bonding.

Other site-specific findings in this report include the following:

- Unlike most U.S. uranium mining sites, which occur in desert or semi-desert, sparsely-populated regions, the Coles Hill site is wet, with annual precipitation equal to about 42 inches. Most importantly, within a radius of 2 to 3 miles, Coles Hill has roughly 250 private wells, at least one dairy and numerous hay / forage fields, which are liable to be impacted.

- Virginia Uranium has failed to present any sort of detailed project proposal, in writing. The verbally-described plans have changed constantly, depending on the audience. Hence the public has no way of reliably knowing the details of the proposed mining and mineral processing methods, or the related impacts.

- The project as proposed may generate at least 28 million tons of solid uranium mill tailings and roughly the same amount of liquid waste. The solid wastes would remain on site **forever**, requiring maintenance **forever**. Uranium mill tailings would contain radionuclides, heavy metals and other toxic elements.

[1] ***All page numbers cited below are the page numbers at the top of the electronic versions of the various documents cited, not the numbers at the bottom of the individual pages.***

- Undiluted tailings liquids may contain **1160 to 1460 times** the existing Safe Drinking Water Act standard for uranium. Undiluted tailings liquids may contain ***2300 to 2900 times*** the allowable uranium concentrations when compared to the **short-term Canadian aquatic life guidelines**.

- The confirmed presence of sulfides in the Coles Hill rock raises the possibility that long-term, active water treatment may be required, in perpetuity.

- Numerous factors (i.e., natural permeability of the rock due to fractures and faults; increased fracturing due to mine blasting; open or leaking boreholes and blastholes; high permeability in the nearby sediments; long-term degradation of tailings liners and other mine structures; and seismic activity) combine to provide long-term pathways for the migration of contaminants into local waters.

- As proposed, the Coles Hill project would require **over 5 billion gallons** of water. During the start-up period, the project would use at least **525.6 million gallons per year.**

- It has been estimated that at least **136 million gallons of ground water (mostly) would flow into the open pit, per year.** This water would become contaminated with numerous radioactive and non-radioactive contaminants. To allow mining, this contaminated water must be pumped out of the pit and discharged to some undefined location.

- The Coles Hill project may use **over 2,030 tons of explosive per year,** releasing potentially-toxic concentrations of nitrate, ammonia, and other organic compounds into the environment.

- Such a project would cause **long-term, chronic degradation of water quality** and increase **water competition** in the region.

- Statistically-adequate **baseline data** (water quality, quantity, etc.) have never been collected, compiled and interpreted, or released to the public. Thus, the public has no reliable "yardstick" against which to demonstrate that changes have occurred, or not.

- There is no credible evidence to indicate that either the Federal or State regulatory agencies have sufficient staff, budgets, or political clout to adequately- oversee and enforce the appropriate regulations.

- All such large-scale uranium projects involve trade-offs, usually some short-term jobs, etc. in exchange for long-term impacts (environmental, socioeconomic, etc.), most of which are paid by future generations. Thus, many of the long-term costs will be subsidized by the public.

Introduction

Purpose and Scope: Uranium mining and processing has been banned in Virginia for many years. An excellent review of the regulatory aspects of uranium mining and milling in Virginia is presented in Rosenberg (1984). During the early 1980s and again today, corporations interested in producing uranium from the Coles Hill site have attempted to change the Virginia statute banning uranium mining in the Commonwealth.

This report provides a site-specific assessment of the Coles Hill site that will host the first uranium mine and mill on the East Coast if Virginia legislators decide to repeal the existing ban. The Coles Hill site is comprised of two uranium deposits controlled by Virginia Uranium, Inc., a wholly-owned subsidiary of a Canadian private company Virginia Uranium Holdings. The Coles Hill site was discovered by Marline Uranium Corp. (Marline) in 1979, which conducted extensive exploratory and development activities jointly with Union Carbide Corporation (Union Carbide).

This paper draws independent conclusions, focusing mostly on *water-related,* technical issues. These opinions are based on review of the original data and reports (1979 to 1984), and the recent, publicly-available, company documents (2007-2010). The information in this report is intended to assist the public and regulators in making better-informed, long-term decisions, not to tell them what should be done.

Background. The technical conclusions in this report are partly based on my involvement in 1983 as a hydrogeological and water quality consultant to Marline and Union Carbide on many of the water-related activities at Coles Hill. Furthermore, over several years I have worked with many of the consultants that produced the Marline Report (1983) and supporting technical reports on this and several other mining / water-related projects. In addition, the conclusions in this report have been shaped by roughly 40 years of related experience at hundreds of mining, natural resource, and industrial sites.

My present involvement was requested and funded by the Roanoke River Basin Association (RRBA). Various aspects of uranium mining are expected to be addressed in the National Academy of Sciences (NAS) report due on December 1, 2011. However, the NAS task statement explicitly excludes site-specific assessments,(http://www8.nationalacademies.org/cp/projectview.aspx?key=49253) which prompted the RRBA to commission this report.

These efforts have been assisted by several members of the Duke University Environmental Law and Policy Clinic (ELPC), directed by Prof. Ryke Longest. Thanks go to Thomas Dominic, Madeleine Foote, Ted Ririe, and Jill Strominger. This group has researched the literature on numerous uranium-related topics.

Two products of this research are located at the **end of this report**; discussions on Environmental Economics and Environmental Health as they pertain to uranium mining and milling*.*

National Academy of Sciences Report on Uranium Mining in Virginia

In November 2008, Virginia Coal and Energy Commission requested that Virginia Polytechnic Institute and State University (VA Tech) commission the National Academy of Sciences (NAS) to prepare a report on uranium mining in Virginia. The NAS report is intended to provide information to assist Virginia legislators to "…determine whether uranium mining, milling and processing can be undertaken in a manner that safeguards the environment, natural and historic resources….." The ongoing NAS study is not designed to give a definite answer to the crucial question of whether uranium mining can be done safely in Virginia. Instead, the scope of the NAS study calls for secondary research, a review of the literature and experiences with uranium mining elsewhere. The statement of work explicitly states that "the study will not make recommendations about whether or not uranium mining should be permitted nor will the study include site-specific assessments." (http://www8.nationalacademies.org/cp/projectview.aspx?key=49253)

VA Tech is considered to be the NAS study's official sponsor and thus was responsible for designing the scope of work for the NAS panel. However, the $1.4 million funding for the NAS report is being provided by Virginia Uranium that also paid VA Tech an additional $300,000 as compensation for overseeing the NAS study process. NAS policy does not permit industry funding to exceed 50 percent of the study costs. (http://www.nationalacademies.org/about/faq.html)

When VA Tech agreed to undertake the task of commissioning the NAS to prepare the uranium mining report, (http://dls.state.va.us/groups/cec/110608/Motion.pdf) it had already been contracted by Virginia Uranium to perform a separate site study at a total cost of $286,000. The total recent funding received by VA Tech and its staff from Virginia Uranium exceeds $1,023,000. Sources for the above information can be found in the VA Tech-Virginia Uranium Agreement, February 2010, and the VA Tech-Virginia Uranium Independent Contractor Agreement, June 2008 and Amendments 1-5; and 2010-2011 Annual Report of Geosciences Department Learning: Undergraduate, available at: http://dls.state.va.us/groups/cec/Uranium/info.htm, Sep. 11, 2011.

Because the NAS study process has been dominated by VA Tech, which received significant funding from Virginia Uranium, the technical and financial independence of these efforts should concern the public.

Coles Hill Site

The site is located in the Roanoke River Basin watershed, 15 miles southeast of Smith Mountain Lake. Virginia Uranium holds minerals rights in the Coles Hill site and adjacent properties. (Coles Hill Preliminary Economic Assessment, Lyntek & BSR Engineering, Dec. 2010, Section 3.2, p. 9).

The Coles Hill site is drained by Mill Creek and Whitehorn Creek and borders the Banister River. The two creeks converge off the site and drain into the Banister, a tributary to the Roanoke River Basin. (Section 7.5, p. 22-23). The Banister empties into Kerr Reservoir, also known as Buggs Island Lake, the second largest reservoir in the United States built by the U.S. Army Corps of Engineers to address massive floods on the Roanoke. http://www.saw.usace.army.mil/jhkerr/index.htm Approximately 1.2 million citizens rely on the Roanoke for drinking water needs downstream of the Coles Hill site, including five naval stations and 770,000 people in the Hampton Roads area. (Joe Bouchard Presentation at 53rd Conservation Forum of the Garden Club, Nov. 3, 2011, Richmond, VA; Tom Leahy, Director, City of Virginia Beach Utilities, Email Response to RRBA's FOIA Request, Jan. 25, 2011).

A fully-operational dairy in the vicinity of the Coles Hill site

Unlike most of the uranium mining sites in the world, Coles Hill is located in a relatively-densely populated area with an average annual precipitation of 42 inches. There are at least 250 private wells within a 2-mile radius of the site. At least one operating dairy and numerous hay and other forage fields lie within roughly a 3-mile radius of the site. [Byron Motley, personal communication, November 2011.] According to the 2010 U.S. Census results, over 1268 people reside within a 3-mile radius of the site.

It is also notable that the Coles Hill site hosts three "Class A FEMA Flood Hazard Zones," which means that in these areas there is a 1% annual chance of flooding and a 26% chance of flooding over a 30-year period. (https://hazards.fema.gov/)[2] These flood zones are contiguous with Mill and Whitehorn Creeks and the Banister River. The site also has discharging springs and several acres of wetlands located within the bounds of the Coles Hill South Exploration Area. (J. P. Gannon, 2009, and DeLorme TopoUSA8 topographic map, www.delorme.com).

[2] Definitions of FEMA Flood Zone Designations, available at https://hazards.fema.gov/

South Meadows Road bordering Coles Hill Site (above).

Spring on the Coles Hill site off South Meadows Road (right)

Mining and Uranium Processing: Basics

Rock containing economically-valuable concentrations of minerals, in this case uranium minerals, is called *ore*. Such ore is excavated from the earth using explosives, forming either immense open pits or underground excavations. Ore is then transported to a processing plant using huge trucks or conveyer belts. Much of the rock removed from an open pit contains metal concentrations that are too low to be economically processed. This material, *waste rock*, is often discarded in huge piles, somewhere on the land surface, often near the pit perimeter.

At the processing plant, the ore is crushed into small particles and massive quantities of process chemicals and water are then added to extract the uranium from the ores. However, these procedures also mobilize dozens of other natural rock components, such as radium, thorium, selenium, molybdenum, arsenic, mercury, *etc*.-- in addition to the uranium. All of these natural contaminants plus the remaining process chemicals are disposed as a liquid-solid waste (containing about 50% of each) called *tailings*. Tailings are discharged into a tailings impoundment. In historical mining jargon, the ore entering a process plant was often referred to as “heads”, and the wastes exiting the plant were called “tails”.

Wastes**.** Active metal-mine operations routinely release chemicals into the surrounding environment from two general sources---the natural, mineralized rock, and the massive quantities of chemicals that are added and utilized throughout the mining and mineral processing activities. The various mineral processing techniques (both physical and chemical) greatly increase the *rates* at which many chemical constituents are released from the mineralized rock.

Mining processes alone (without mineral processing) expose, blast, and fragment formerly buried rock that contains high concentrations of dozens of different metals (radioactive and non-radioactive, including uranium), metal-like elements and other rock minerals. These mining actions greatly increase the surface area of the rock particles, expose them to air and other gases and bacteria, which increase the tendency for these mineralized rocks to chemically-react with the local waters. Thus, the natural rock components are released into nearby waters, both as dissolved contaminants and sediment particles. Such processes increase the concentrations of contaminants and sediment particles in the environment, *even when the waters are not acidic.* However, if significant concentrations of sulfide minerals, especially various forms of iron sulfide (pyrite, marcasite, *etc*.) are present in the exposed rocks, natural sulfuric acid is formed. The rates of acid production are greatly sped up by the presence of specific species of bacteria, which then increase the rate at which the uranium, other metals, metal-like elements, and other rock contaminants are released into the environment.

Thus, several sources of mine rock release contaminants into the environment: the walls of the open pit, walls of the underground workings, waste rock piles, tailings, and road cuts.

Uranium process wastes*, tailings,* may be either strongly acidic (with initial pHs often between 1.5 and 2.5) or strongly alkaline (initial pHs between about 9.5 and 12.0). As mentioned, they contain both the natural rock contaminants and the remaining process chemicals—many of which are potentially toxic. As the tailings age, and the solids react with the liquids, air, and bacteria, the liquid pH may change (up or down) drastically over many years. *Both high and low pH* environments cause many of the chemical components to go into solution, increasing their dissolved concentrations. Thus, such contaminants from either high or low pH waters will be mobilized and released into the environment.

The Coles Hill ores contain *relatively low* uranium concentrations. Thus, it is most economic to consider open-pit mining methods, which are generally less expensive than underground methods. The Marline Report (1983) indicated that the final depth of the pit would be roughly 850 feet. Any modern pit might be much larger and deeper, however. Once such a deep pit is excavated, it acts as a “sink”, collecting local ground water. Ground and surface waters (and rainfall) contact the mineralized rock of the pit floor and walls, which routinely causes the pit water to become contaminated. Pit water must be pumped out during active operations to allow mining to occur. Because pit waters are often contaminated, they are usually discharged to the tailings impoundment rather than released directly into the environment.

At Coles Hill, Marline stated that the final pit would fill with water and remain, post-closure, as a lake covering roughly 100 acres---available for “unrestricted use”. The modern Virginia Uranium documents mention that underground processes may also be employed, but no details are provided. Such underground workings would also act as “sinks” for water inflow, resulting in water contamination similar to open pit processes.

***Other Mine Contaminant Sources*.** In addition to the natural rock components (metals / metalloids, radioactivity, sediments, etc.), mine waters are also routinely contaminated by: explosive residues, process chemicals, fuels, oils and greases, antifreeze, sewage waste, herbicides and pesticides.

These contaminant sources release forms of chemicals into local waters that are extremely toxic to fish and other aquatic life. Many are also toxic to humans and other animals if ingested, in some cases acutely, or slowly over significant periods of time. For example, residues from the massive use of explosives, release ammonia, nitrate and residues of fuel oil into the environment. Free ammonia is roughly as toxic to cold-water fish as free cyanide. Both gasoline and diesel release components that can act as cancer-causing agents to many organisms. Mining companies routinely spray used oil and other chemicals onto roads to suppress the dust, which releases additional contaminants.

The Important Questions

What recent information has Virginia Uranium released?

Recent Virginia Uranium documents, such as the Technical Reports (Christopher, 2007; Behre Dolbear, and others, 2009) and the Preliminary Economic Report (Lyntek Inc. & BRS Engineering, 2010) were prepared to comply with various Canadian prospective shareholder regulations (i.e. National Instrument 43-101, etc.).

All three reports provide considerable detail on the mineral resources[3] at the Coles Hill site, but present incomplete and thus misleading information about possible environmental impacts and related economic costs. Specifically, these Virginia Uranium reports fail to present the operational and technical detail necessary for the public, investors and regulators to realistically evaluate future environmental contamination, increased water resource competition, and unforeseen public and investor liabilities. Overall, these reports have the tone of public relations documents.

[3] The Canadian Institute of Mining, Metallurgy, and Petroleum defines mineral resources as follows: “A Mineral Resource is a concentration or occurrence of diamonds, natural solid inorganic material, or natural solid fossilized organic material including base and precious metals, coal, and industrial minerals in or on the Earth’s crust in such form and quantity and of such a grade or quality that it has reasonable prospects for economic extraction. The location, quantity, grade, geological characteristics and continuity of a Mineral Resource are known, estimated or interpreted from specific geological evidence and knowledge.” Mineral resources are different from the mineral reserves that are the economically mineable part of Measured or Indicated Mineral Resources, as demonstrated by at least a preliminary feasibility study.” The Coles Hill Preliminary Economic Assessment addresses only mineral resources, as Virginia Uranium is yet to complete a feasibility study.

These reports repeatedly imply that no significant environmental liabilities exist. For example, page 17 of the 2009 Technical Report (Behre Dolbear, and others, 2009) states: “Neither Behre Dolbear nor PAC is aware of any environmental liabilities related to the CHUP.” Page 68 of the same Technical Report states: “The analyses (whole rock / ore analyses) show a relatively clean ore, that is it does not contain quantities of heavy metals that are typical of uranium ores of the southwestern United States.”

These sorts of half-truths were taken almost *verbatim* from the 1983 Marline Report [Dravo Engineers, Inc (1983 / 84)], which was submitted to both the Virginia Uranium Administrative Group in 1983 and the NAS panel in 2011. For example, the Marline Report, Vol. 2, page 70 states: “The analyses show that this is a relatively clean ore, that is, it does not contain quantities of heavy metals that are typical of uranium ores of the southwestern United States.” When referring to the chemical characteristics of the tailings, page 142 of the same Marline Report, Vol. 2, states: *“Aside from the residual uranium, the concentrations of other chemical impurities in the tailings will be insignificant.”*

All such statements are at least misleading and intended to imply that these wastes (waste rock, tailings) will not release contaminants into the environment. Such conclusions are not substantiated by the site-specific test data or the professional literature, as is demonstrated below.

What are some serious limitations of the historic (1980s) Coles Hill studies?

While the technical aspects of the specific hydrogeological and water quality studies undertaken by the individual water-related consultants to Marline and Union Carbide in the 1980s were generally competent, the final language used in the Marline Report (1983) was often overly-simplified in ways that implied few if any negative impacts would ever occur. These “softened” conclusions are often inconsistent with the findings and language of the original technical reports.

Predictions made about the expected, largely-benign water quality at numerous other uranium mining and processing facilities by some of these same consultants have proven to be *overly optimistic* and incorrect (i.e. the Midnight and Schwartzwalder Mines; the Uravan and Cotter Mills). All of these sites have generated “unforeseen” remediation, water treatment and litigation costs that have been borne largely by the public. Thus, taxpayers have subsidized the real costs for uranium mining and milling.

Predictions of post-closure water quality at metal mines, in general, suffer from tremendous degrees of error when one compares specific predictions with what actually occurred [Kuipers & Maest (2006); Moran (2000); Pilkey & Pilkey (2007)]. Similar percentages of error occur when one compares predicted volumes of water to be pumped from metal-mine pits / workings with measured volumes pumped during actual, long-term operations (personal experience).

Have metallurgical tests been performed on these Coles Hill ores?

Feasibility Studies and Reports are major sources of detailed, technical information on the chemical compositions of uranium and other metal ores and the resulting waste products, including tailings solids and liquids. Such reports are prepared to inform the operating company and prospective investors about the percentages of uranium or other metal products that can be commercially extracted from the ores, and the detailed chemical compositions of the typical waste products resulting from the use of specific chemical and physical processes.

A careful reading of the Marline Report (1983), Vol. 2, pg. 65, and recent Virginia Uranium documents reveals that several episodes of feasibility / metallurgical testing were conducted for Marline and Union Carbide during the early 1980s [i.e. Colorado School of Mines Research Institute (1982); Virginia Tech; Dravo (1981, 1983 / 84); Hazen Research; Pincock, Allen & Holt (1982)].

The recent Virginia Uranium reports fail to present any of the detailed chemical composition information from these feasibility / metallurgical test reports, and instead imply that the liquid and solid wastes *are of little environmental consequence*. Nevertheless, the Preliminary Economic Assessment [Lyntek (2010)] states on page 68: "In the opinion of Lyntek, this work was performed by credible organizations whose work was respected and is worthy of this level of feasibility study." Despite this statement, Lyntek failed to include any of these trustworthy feasibility / metallurgical test details.

What chemical contaminants will be in the mine wastes?

Tailings Liquids: Chemical Compositions*.* Volume 1A of the 1983 Marline Report [Dravo Engineers, Inc (1983 / 84)], page 69 is a table showing the chemical and radiochemical compositions of typical tailings liquids from the Coles Hill (formerly known as the Swanson Project) uranium site, resulting from both acid and alkaline leach techniques. It is unclear which of the testing laboratories provided the original tailings data presented in this table. The metallurgical tests were intended to simulate the commercial extraction of uranium from the Coles Hill ores.

These data show that the Marline tailings (test) solutions contained concentrations of numerous contaminants potentially toxic to, as a minimum, aquatic organisms in all of the acid or alkaline solutions. Some of the contaminants present at environmentally-unacceptable concentrations were: arsenic, cadmium, chromium, copper, iron, molybdenum, lead, vanadium, zinc, uranium, radium-226, gross alpha and beta radioactivity, ammonia, fluoride, chloride, sulfate, sodium, together with total dissolved solids (TDS) and pH. It is notable that these liquid wastes contained 44,000 micrograms per liter (equivalent to 44,000 parts per billion) of uranium as U_3O_8 from the acid leach and 35,000 micrograms per liter of uranium from the alkaline leach.

Uranium wastes are potentially toxic not simply due to the emitted radioactivity, but also due to the **chemical toxicity** of many components, including elemental uranium. While there was no formal uranium standard for drinking water when these Marline studies were conducted (early 1980s), it was widely reported in the technical literature that elemental uranium was potentially toxic to humans and other organisms and that the U.S. Environmental Protection Agency (EPA) was considering establishing a drinking water standard in the range of 10 to 50 micrograms per liter [Cothern and others (1982); US EPA (1983); personal experience)].

A 1982 preprint of the Cothern and others (1982) article recommended a uranium drinking water standard of 10 picocuries per liter (radioactivity from uranium), which is equivalent to 14.7 micrograms per liter (mass of elemental uranium). The interim regulations for radioactivity in drinking water were promulgated in 1976 (Federal Register, Friday, 9 July, 1976, p. 28402).

In 2003 the US EPA adopted a drinking water standard for elemental uranium of 30 micrograms per liter. Thus the undiluted tailings liquids studied in the Marline metallurgical testing and reported in Volume 1A of the 1983 Marline Report, page 69 (Table B.2.3-4), contained roughly **1160 to 1460 times** the existing U.S. drinking water standard for uranium.

While the Marline Report (1983) argues that most of these contaminants would be reduced to environmentally-insignificant concentrations by attenuation on various types of clays and other sediments, this argument has proven to be overly-optimistic at dozens of other formerly-operating uranium mine and mill sites. In fact, the same sorts of column tests, described in Volume 1A of the Marline Report (1983), pages 68 through 73 (*and performed by some of the same Marline consultants)* have also failed to realistically predict the actual concentrations, significantly underestimating long-term contaminant concentrations and migration for other uranium projects. Clearly the statement made on page 142 of the Marline Report, Vol. 2, is at best misleading: “Aside from the residual uranium, the concentrations of other chemical impurities in the tailings will be insignificant.”

The tailings chemical data presented above refer only to the *liquid portions* of the tailings, which often make up roughly 50 percent of tailings volume. The remaining 50 percent of the tailings solids would likely contain even higher concentrations of these contaminants. The Coles Hill Preliminary Economic Assessment (Lyntek (2010), Table 25.1, p. 103) estimates that the operations will generate over 28 million tons of solid uranium mill tailings waste. A significant portion of these solid tailings wastes, **long-term,** would react with local waters, gases and bacteria, and be mobilized into the local ground and surface waters and possibly soils. **These wastes will remain on the site forever.**

What volumes of contaminated liquid are estimated to seep from the tailings?

The Marline Report authors estimated that liquid seepage from the tailings would be roughly 0.10 to 0.15 gpm per acre [Marline Rept., Vol. 2: p.156] and that the tailings area was approximately 200 acres [Marline Rept., Vol. 2: p. 146]. Thus the seepage of untreated tailings liquids would be roughly 52,560 to 78,840 gallons per year, which would be between 1,576,800 and 2,365,200 gallons after 30 years. All such estimates are subject to huge margins of error and are usually overly-optimistic when presented in environmental documents.

The Coles Hill Preliminary Economic Assessment states that the Coles Hill site will host eight (8) "surface impoundments" up to 40 acres each that will hold over 19 million tons of solid waste, not including liquids. (Lyntek (2010), Sections 18.4.4 and 18.5.4; Table 18.3). Under US Nuclear Regulatory Commission (NRC) regulations, "impoundments are limited to 40 acres in size; however, a facility can have multiple impoundments and typically total on the order of hundreds of acres." (http://www.nrc.gov/materials/uranium-recovery/extraction-methods/comparison.html)

In a public presentation on November 3, 2011 at the Garden Club Forum in Richmond, Virginia Uranium's representative indicated the company's intention to place tailings in underground facilities. While US NRC regulations favor the below grade disposal of uranium mill tailings, above grade disposal is permitted where:

1. "a ground-water formation is relatively close to the surface or not very well isolated by overlying soils and rock."

2. "geologic and topographic conditions …make full below grade burial impracticable: For example, bedrock may be sufficiently near the surface that blasting would be required to excavate a disposal pit at excessive cost, and more suitable alternative sites are not available. (Appendix A to Part 40—Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material From Ores Processed Primarily for Their Source Material Content, Criterion 3, http://www.nrc.gov/reading-rm/doc-collections/cfr/part040/part040-appa.html).

Will the Coles Hill rocks and wastes release acidic seepage, long-term?

We don't know. The publicly-available data lacks the specific details to answer such questions. The Preliminary Economic Assessment (Lyntek Inc. & BRS, 2010, p.35) and Jerden (2001, pg. 25, 26, 63) mention the presence of pyrite in the Coles Hill rocks, but none of the relevant reports (historic or modern) provide any detailed data on the percentages of sulfides or detailed static or kinetic testing of these rocks. Hence the public has no information on which to evaluate the **long-term** possibility of generating acid drainage from the waste rock, tailings, or pit / mine walls. Even when tailings are originally deposited as alkaline materials, they can become acid after many years of chemical / biological reaction. Furthermore, tailings which have alkaline or near-neutral pH can also release potentially-toxic concentrations of contaminants into locals waters and soils.

Waste rock with sulfide concentrations as low as 0.2 % eventually became acid at the Zortman-Landusky Mine, U.S.A, leading to unfunded water treatment costs for the public currently in the tens-of-millions of dollars (personal experience). In an industry-funded study of **100s of metal-sulfide mines throughout North America**, Todd and Struhsacker (1997) found that **all sites exhibited some degree of water quality degradation, long-term.** These were predominantly metal-sulfide mines, but the same issues apply where uranium ores contain significant sulfide content.

Will there be impacts to local ground waters?

The Marline Report (1983) contains several sections that discuss the hydrogeology and water quality of the Coles Hill site [i.e. Vols. 1, 1A, 2, and 5]. These studies, while disjointed and poorly-coordinated, clearly describe all of the site geologic formations as being water-bearing, with numerous wells completed in the region. They also report the presence of several springs, some located along fault traces and describe some of the faults as capable of transmitting water. The permeability of the bedrock units is mostly via faults and fractures, but the crystalline bedrock generally yielded little water in the pump test wells. However, none of these test wells was drilled more than 200 feet deep, and the proposed mine pit was to be 850 feet deep. Thus, the available data may greatly underestimate the volumes of water produced from the deeper bedrock zones, especially after they are fractured due to blasting.

In addition, both the Marline Report and the recent Virginia Uranium reports state that *at least two hundred boreholes and wells* (exploration, geotechnical and monitoring / hydrogeological) have been drilled and completed on the site since at least the early 1980s. Page 38 of Marline Report, Vol. 2 estimated that 2300 blast holes, roughly 45 feet in depth, would be drilled *each year*. The Preliminary Economic Assessment (Lyntek, 2010, p.18), states that: “Exploration holes drilled by Marline and Virginia Uranium have been abandoned by cementing them from bottom to top as required by Virginia state regulations.” Unfortunately, none of the publicly-available documents provide technical information (i.e. abandonment logs) substantiating that these boreholes were correctly abandoned, or that they have been correctly maintained since the early 1980s. Such positive statements are frequently made in uranium and other mine environmental documents, but are often proven to be incorrect (i.e. Moran, 2010). Typically, many such boreholes later act as preferred pathways for ground water flow, both vertically and horizontally.

Thus, numerous factors (i.e. natural permeability due to fractures and faults; increased fracturing due to mine blasting; open or leaking boreholes and blastholes; high permeability in the nearby sediments; long-term degradation of tailings liners and other mine structures; seismic activity) combine to provide long-term pathways for the migration of contaminants into local waters. Again, it must be recalled that the mine / process wastes (waste rock, tailings, etc.) *will remain onsite forever.* It is generally the slow, chronic, semi-invisible, chemical reactions and seepage of effluents that routinely produce the long-term unforeseen impacts to water resources and costs for taxpayers. No waste facilities can remain stabilized unless funds are available to maintain the facilities, forever.

How much water will be used by the proposed Virginia Uranium project?

At present, the public can only rely on unsubstantiated Virginia Uranium statements; no recent, detailed test data have been provided. Virginia Uranium states in the Preliminary Economic Assessment (Lyntek, 2010, p. 68): "….the required water supply to the plant during standard operations is 270 gpm (0.6 cfs); during startup the required supply is 1000 gpm (2.2 cfs)." This doesn't sound like much until one realizes that 1000 gallons per minute (gpm) is equivalent to **525.6 million gallons per year,** and Virginia Uranium estimates that project startup may extend for the first one to two years (Lyntek, 2010, p. 109).

The estimated water use during operations appears minor when stated simply as 270 gpm, but this volume is equivalent to **388,800 gallons per day, or 141,912,000 gallons per year. That is, about 142 million gallons per year. Virginia Uranium states that the life of the mine (LOM) is estimated to be between 30 and 35 years (**Lyntek, Dec. 2010, p. 68). **Thus the project would consume over 5 billion gallons of water**.

We have no modern, detailed information on the volumes of water to be used, but based on the Marline Report (1983, Executive Summary, p.31), merely the inflow of water into the open pit is estimated to be 258 gpm, which is equivalent to **135,694,842 gallons per year; that is 136 million gallons per year of pit inflow.**

The public must be reminded that these data are from 1983. The proposed pit was then estimated to be about 850 feet deep, but none of the wells constructed to evaluate the volumes of ground water entering the pit were deep enough to make reliable estimates of pit inflow; none were greater than 200 feet deep (MUC / UCC 1983, Vols. 1 & 5).

Will the water quality be impacted?

Standard mining operations **always degrade water quality** to some extent by:

- blasting, fracturing and crushing mineralized rocks, which greatly increases rates of the chemical reaction of these rocks with water, air / gases and bacteria, releasing numerous potentially-toxic compounds into ground and surface waters;

- use of tremendous quantities of blasting compounds, releasing toxic residues;
- release of process chemicals used to extract uranium from the ores;
- use of massive volumes of fuels (gasoline, diesel), oils, greases, herbicides, pesticides, etc., which are released into the environment.

Virginia Uranium has not revealed whether the proposed operations would be either open-pit, underground, or a combination of both. However, it is obvious that the majority of the millions of gallons of pit inflow waters would come in contact with the mineralized rock of the pit walls and floor, and with the explosive residues, such as nitrates, ammonia, various organic compounds, and fuel residues. The Marline Report, Vol. 2, pg. 39 stated that the project as proposed in 1983 would use an estimated **2,030 tons per year of ANFO explosives** (ANFO = ammonium nitrate and fuel oil). Clearly the modern project proposed in the recent Virginia Uranium reports is likely to move much greater volumes of ore and generate much greater volumes of waste as compared to the 1983 plan. Hence much greater volumes of explosive residues containing nitrate, ammonia, and other organic compounds would be released into the environment.

Inevitably, the quality of site surface and ground waters would be degraded through the proposed activities. This would include degradation of water quality of pit water inflows, underground water inflows, tailings effluents, and discharges from waste rock accumulations.

Metallurgical tests conducted by Marline and Union Carbide (1982-83) provide more specific evidence that the mineralized rocks of the Coles Hill deposits are chemically reactive and release potentially-toxic concentrations of numerous trace contaminants into the tailings waters. Elevated chemical constituent concentrations in water quality data collected by Marline and Union Carbide consultants also show that the site ores are chemically-reactive with local surface and ground waters.

Jerden (2001, p. 2) stated that the dissolved uranium concentrations in Coles Hill ground waters would likely be limited to about 20 micrograms per liter due to the high phosphate content of the waters. This prediction is clearly unsupportable by data collected by Marline and Union Carbide. For example, water samples from a depth of 80 feet in well M-5 showed dissolved uranium concentrations to be 200-220 micrograms per liter, ten times what was theoretically predicted (Marline Report, 1983, V. 5, p. 188 & 197).

Would the release of tailings effluents into local rivers harm the aquatic life?

As described above, the tailings liquids would contain hundreds of different chemical compounds, many of which could be toxic to various aquatic organisms. The details are too complex to cover here, but it is instructive to investigate only a few factors. Firstly, the Canadian government obviously considers uranium toxic to aquatic organisms because it has recommended that short-term exposures of such organisms to dissolved uranium not exceed 33 micrograms per liter (equivalent to 33 parts per billion). This recommendation is applicable to a spill event. The Canadian government recommends that long-term, chronic exposures not exceed 15 micrograms per liter of dissolved uranium (http://ceqg-rcqe.ccme.ca/). Recall that the tailings liquids reported in the Marline report contained between 35,000 and 44,000 micrograms per liter of dissolved uranium. Thus, these effluents contained roughly *2300 to 2900 times* the allowable uranium concentrations when compared to the short-term Canadian aquatic life guidelines.

These effluents, as described above, would contain numerous other chemical constituents that are also potentially toxic to fish, for example, such as selenium, copper, ammonia, etc.

How will the public be able to demonstrate that water quality has been impacted (or not) in the future? [Importance of Baseline Data.]

***Baseline Data**.* With respect to mining projects, most water scientists and regulatory agencies consider baseline as those conditions that existed *prior to the commencement of any active mining operations.* Even the Nuclear Regulatory Commission (NRC*)* requires that pre-mining baseline conditions be defined before licensing [of *In-Situ* Leach sites] (US NRC, 2003, pg. 2-24).

Baseline ground water quality samples are usually collected at least quarterly for a full calendar year from representative springs and wells within a significant radius of the proposed project area (often 1 to 2 miles of the project boundary)—prior to the start of any mine activities. Similar detailed baseline sampling is routinely conducted at all potentially-impacted surface water sites. Baseline data are only truly meaningful if the number of samples analyzed from each site is sufficient to allow a statistical analysis of the variability by sampling site, region and water-bearing unit. That is, simply having one or two samples from a site is not adequate to define baseline conditions.

For mining projects, baseline data should also, *ideally*, be collected prior to the onset of *detailed exploration drilling*. The drilling, well-completion and pumping processes can alter the geochemical conditions in the subsurface, thereby changing the original water chemistry and altering the baseline. It is likely that the water quality of the local wells may have changed since they were drilled in 1983 (and earlier) due to geochemical and bacteriological reactions that often occur through time in such boreholes and wells [i.e. Abitz (2010); Chapelle (1994); Gotkowitz et. al. (2004); Leybourne et. al. (2009); Moran (1976)].

One of the stated tasks of the NAS uranium mining report is to identify baseline data related to uranium activities in Virginia. Without such reliable, pre-operational data (especially water quality and quantity) there is no “yardstick” against which to evaluate future changes and impacts to the water resources. Unfortunately, the present NAS efforts seem to be relying on “baseline” data provided largely by interested parties, the uranium mine proponents themselves.

The baseline data provided by Marline and Union Carbide in the Marline Report (1983) are limited in number; in most cases there is only one analysis for each ground water site, which prevents us from understanding the actual range of natural water quality and seasonal changes. The contractors followed sampling procedures authored by Moran (myself) and Rouse (1981), and the quality of the individual samples appears reasonable.

Some baseline data from 1979-81, as a minimum, have not been included in the Marline Report data. These include data from Marline Uranium Corp. (1983, Mar. 29); and Geological Resources, Inc. (1981), as a minimum. It appears that some Virginia Uranium contractors may be collecting additional baseline data, but these details are not available to the general public.

Are there other long-term impacts to consider?

Seismic Hazards*.* The wastes from Coles Hill or any similar project will remain onsite **forever***.* Even the Marline Report (Vol. 1, pg. 41) states, a bit optimistically, that the functional life of the tailings is considered to be 1000 years. Thus, the site facilities are expected to experience **significant seismic events.** The August 2011 earthquake in the Piedmont region (5.8 Richter magnitude) corroborates this concern.

Flooding**.** Again, the Marline Report (Vol. 1, pg. 73, 83) states that *flooding can occur at any time of year.* A recent report (Rogers, 2011, Sept.) compiled by the Blue Ridge Environmental Defense League documents that the Coles Hill site is prone to flooding by both severe overland flows and high volumes of ground water discharge. The report suggests that storage of uranium tailings there would present a high risk of chronic and/or catastrophic release of radioactive contamination into the aquatic environment.

In February 2011, the City of Virginia Beach released a study that investigated the potential impacts of a uranium tailings release on downstream water sources. Specifically, the City focused on the potential of a catastrophic failure of a uranium-tailings containment structure and subsequent discharge of uranium tailings into the Banister or Roanoke Rivers and the resulting radioactive contamination in downstream water bodies including the Kerr Reservoir. The study aimed to estimate the amount of uranium-contaminated sediment and water that might reach Kerr Reservoir under normal and extreme precipitation events, and estimate the potential increase in radioactivity levels and other contaminants in Kerr Reservoir (Baker, 2011).

The study showed that radiological contaminants (radium-226 and thorium-230) in the water column and sediments in Banister and Roanoke Rivers and the Kerr Reservoir could result in water column concentrations exceeding by 10-20 times the regulatory standards for combined radium-226 and 228 in drinking water for up to two years. The study also predicted that particulate contaminants in sediments would be re-suspended during high flows and that Kerr Reservoir would serve as a permanent trap for particulate contaminants.

Clearly the concerns above pertain to both radioactive and non-radioactive contaminants. Thus, all mine wastes (waste rock, tailings, pit waters, etc.) must be maintained in a stable condition under the extreme Virginia precipitation conditions, **forever**.

What actual, long-term financial and environmental impacts have occurred at other uranium operations?

In this paper it is only possible to mention some of the summary conclusions on this topic. *Additional details related to the economic and health impacts were prepared by members of the Duke University Environmental Law and Policy Clinic (ELPC) and are presented at the* ***end of this report****.*

Most past U.S. uranium mining and milling has been conducted in the arid West, usually in regions quite isolated from significant populations. Many of these sites receive less than 10 inches of annual precipitation, sometimes much less. The Coles Hill site receives roughly 42 inches annual precipitation, rendering long-term water and waste management much more difficult.

Essentially all of the western sites have generated long-term environmental contamination that have already cost the federal government more than *$2 billion* dollars in remediation costs, and there is *no end in sight*. (Nuclear Power: Still Not Viable Without Taxpayer Subsidies" Union of Concerned Scientists, Feb. 2011). Admittedly, the operating and disposal procedures originally used at most of these sites were much more primitive than would be employed today. However, the long-term, "big picture" is not encouraging.

The public must understand that uranium development has traditionally been *economically-subsidized* by numerous practices of the federal government. A few examples include: 1) exploration was subsidized by financial aid from the Defense Minerals Exploration Administration, which granted to qualified applicants seventy-five percent of the cost of uranium exploration; 2) The AEC's (Atomic Energy Commission) direct purchase of source material created a boom in uranium production in the western states; 3) The AEC established guaranteed minimum prices for its purchases of uranium ores (Rosenberg, 1984). In general, uranium (and other mining) companies have utilized unlimited volumes of water without charge. Hence, simple cost-benefit analyses have little or no relevance to the profits or losses imposed on the general public [see Duke ELPC discussions at end of this paper; Powers (2008); WISE (2011a,b)].

One existing site, the **Cotter Uranium mill in Canon City, Colorado**, will suffice as an instructive example on many of the "big picture" issues the Virginia public needs to consider. The mill, which sits outside the city of Canon City and up-gradient from the Arkansas River, has been operated off and on between1958 and 2005. Throughout this time Cotter received dozens of violation notices for contaminating the surface and ground waters (including local wells), soils and air. Nevertheless, after short closures, the mill reopened and continued to operate until 2005. The original tailings impoundment and a newer one *constructed under the updated regulations* both leaked contaminants. In 1984, the site was put on the Superfund list. Since 2005 it has been in the process of decommissioning, although in 2009, Cotter informed the State of Colorado of its intent to refurbish the mill to accept uranium ore from the Mt. Taylor Mine in New Mexico. Cotter had proposed to move forward on this plan to refurbish the mill despite ongoing and newly exposed off-site ground water contamination plumes of radioactive and toxic pollutants including uranium, molybdenum, and trichloroethylene (TCE). In response to this situation, in 2010, the Colorado General Assembly passed HB 10-1348, which was signed into law and, among other things, required Cotter to fully remediate all contamination plumes prior to being eligible to apply to accept any new sources of mill material.

Despite the intent of the new law to further clean up the site, the State of Colorado Department of Public Health and Environment (CDPHE) has been unable or unwilling to require needed updates to the outdated decommissioning plan or require adequate financial assurance (bonds) sufficient to pay for the needed cleanup. As a result, the local community organization, Colorado Citizens Against Toxic Waste (CCAT), has brought suit in state court against CDPHE seeking to require a comprehensive update to the clean-up plans, improved and meaningful public involvement, and an adequate bond. This case is currently pending, with a result not expected until mid-2012 at the earliest.

In 2009, the State of Colorado required Cotter to post a financial bond of $43 million. At present, Cotter had paid only $20.8 million of this amount. As of the Fall of 2011, Cotter has proposed to re-open the mill to process uranium ores from several mine sites. Local waters and soils are still contaminated and would likely require construction of another tailings impoundment, together with collection and active treatment of the contaminated ground waters.

Cotter Corp. has also owned the Schwartzwalder Mine near Denver (since 1965), which originally supplied ore to the Cotter Mill. The mine has been contaminating the ground and surface waters up-gradient of one of the City of Denver's main water supply reservoirs for decades. As of the Fall of 2011, ground waters near the mine contained several hundred micrograms per liter of uranium (and other contaminants), and the City and State have been unable to force Cotter to actively treat the waters. The present financial bond is roughly $1.2 million dollars---totally inadequate to handle the problems. Throughout these decades, Cotter was owned by major national corporations; firstly Consolidated Edison and since 2000, General Atomics. The Cotter details above come from verbal and written communications with Jeff C. Parsons, attorney, Western Mining Action Project, (October 2011), and from personal experience as a consultant to the attorneys for Cotter Corp. from 1981 through 1983. Other details come from a

series of articles in the Denver Post, most of which are from 2011. A few examples can be found at:
http://www.denverpost.com/news/ci_19202878?source=rsshomemiss
http://www.denverpost.com/news/ci_19174721
http://www.denverpost.com/news/ci_19016447

A similar reality can be found at the closed and operating uranium sites in Canada. The main difference is that most of these sites are quite remote from significant Canadian population centers, so the impacts are less obvious to the general public.

The Rabbit Lake site in northern Saskatchewan serves as an informative example. The site is *actively-operating* and has been operating since 1975 [http://www.cameco.com/mining/rabbit_lake/]. A 2009 review of all of Canada's operating uranium sites [Canadian Nuclear Safety Commission (2010)] shows that in 2009, Rabbit Lake **effluents** had an average monthly uranium concentration of 0.0765 mg/L (77 micrograms / L). Page 15 of this 2009 Annual report (CNSC, 2010) states that the load of uranium released to the environment was *340 kilograms (equivalent to 748 pounds of uranium).* One must assume this is the annual uranium load, but the table fails to make clear whether this is per month or per year! Because the reader does not know the effluent discharge volumes, it is not possible to rectify this uncertainty. In either case, these are tremendous quantities of uranium being released into the local environment, along with many other constituents. It is also informative to note that Saskatchewan allows these sites to discharge up to (2.5 mg/L) of uranium in their effluents (WISE 2011b). That is, 2,500 micrograms per liter. Recall that the Canadian long-term aquatic life guideline is 15 micrograms per liter.

Can the State of Virginia Effectively Oversee Uranium Activities?

For numerous reasons, regulatory enforcement at uranium mine and processing sites has been lax historically. National trends toward deregulation in many arenas (financial, environmental, etc.), together with the weak economy make it likely that enforcement of uranium industry-related regulations would be inadequate (Burnley, 2011). Most federal and state agencies simply do not have adequate budgets and trained staff, or the political mandate needed to reliably oversee such activities and enforce the regulations.

What techniques are most useful to assure that the company pays for long-term impacts, and the public doesn't?

Financial Assurance & Long-term Facility Management*.* Financial Assurance vehicles (bonds or insurance) at mining sites have proven useful at minimizing unforeseen costs to the public. It is now common for states to require financial bonds for large metal-mine operations in the range of tens to hundreds of millions of dollars. Unfortunately, the following is often the case:

1. Financial bonds generally are based on overly-optimistic assumptions about future water quality, thereby under-estimating costs. Kuipers (2000) conducted a survey of bonding practices at metal mines throughout the western U.S. and found that the bond amounts available were hundreds of millions of dollars below amounts necessary to conduct actual clean-ups. Many of the "problem" sites have been foreign-owned entities, especially those with their corporate headquarters and assets based in Canada.

2. Many uranium mines and processing facilities have generated *long-term* water quality contamination. If the public desires to use these waters for most other purposes (i.e. irrigation, livestock watering, municipal, domestic), construction and operation of high-cost, *active* water treatment plants is required to clean the waters, sometimes *in perpetuity.*

3. Predictions of future aquifer restoration success made by the project proponents seldom use truly conservative assumptions. Calculation of financial assurance amounts made by representatives of the party that stands to profit from project licensing represent an extreme conflict of interest.

4. The technical literature is filled with documentation that quantitative predictions of future water quality at specific sites cannot be done reliably [Sarewitz, et. al. (2000); Moran (2000); Pilkey & Pilkey-Jarvis(2007); Kuipers & Maest (2006)], and the general failure to restore aquifers back to pre-operational baseline concentrations support this. At an academic level, this approach is totally rejected because it assumes one can make accurate and precise *deterministic* predictions.

Financial Assurance calculations should be made by some independent party, not paid or directed by the project proponents. Specific financial assurance amounts and mechanisms should be made public prior to award of any licenses. To ensure protection of the general public, such financial assurance vehicles (bonds, etc.) should be made with the parent corporation, not simply the local operating entity.

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<u>About Robert Moran</u>

Dr. Robert Moran has more than thirty-nine years of domestic and international experience in conducting and managing water quality, geochemical and hydrogeologic work for private investors, industrial clients, tribal and citizens groups, NGO's, law firms, and governmental agencies at all levels. Much of his technical expertise involves the quality and geochemistry of natural and contaminated waters and sediments as related to mining, nuclear fuel cycle sites, industrial development, geothermal resources, hazardous wastes, and water supply development. In addition, Dr. Moran has significant experience in the application of remote sensing to natural resource issues, development of resource policy, and litigation support. He has often taught courses to technical and general audiences, and has given expert testimony on numerous occasions. Countries worked in include: Australia, Greece, Bulgaria, Mali, Senegal, Guinea, Gambia, Ghana, South Africa, Iraqi Kurdistan, Oman, Pakistan, Kazakhstan, Kyrgyzstan, Mongolia, Romania, Russia (Buryatia), Papua New Guinea, Argentina, Bolivia, Chile, Colombia, Guatemala, Honduras, Mexico, Peru, El Salvador, Belgium, Canada, Great Britain, United States.

EDUCATION

University of Texas, Austin: Ph.D., Geological Sciences, 1974
San Francisco State College: B.A., Zoology, 1966

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Michael-Moran Assoc., LLC, Partner, 2003 to present
Moran and Associates, President, 1983 to 1992; 1996 to 2003
Woodward-Clyde Consultants, Senior Consulting Geochemist, 1992 to 1996
Gibbs and Hill, Inc., Senior Hydrogeologist, 1981 to 1983
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Tetra Tech Int'l. / Sultanate of Oman, Senior Hydrogeologist, 1979 to 1980
Science Applications, Inc., Geochemist/Hydrologist, 1978 to 1979
U.S. Geological Survey, Water Resources Division, Hydrologist/Geochemist, 1972 to 1978
Texas Bureau of Economic Geology, Research Scientist Assistant, 1970 to 1971

APPENDIX

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To: Robert Moran, Ph.D.
From: Duke ELPC, Thomas Dominic, Madeleine Foote, Ted Ririe, Jill Strominger
Date: 27 October 2011
Re: Researched Answers to Important Questions about Uranium Mining, prepared on behalf of RRBA.

Economics Considerations of Uranium Mining (Madeleine Foote)

As the Virginia General Assembly debates the issue of lifting Virginia's current ban on uranium mining, it is essential that they consider all of the economic ramifications of their decision. Virginia Uranium Inc., the company that is pushing to have the uranium mining ban lifted in order to develop the Coles Hill site, has touted the benefits of the project, including jobs for an economically depressed area and new revenue streams for local and state coffers. These benefits, while important, are not the only side of the story; it is essential to also comprehend the costs of allowing uranium mining in Virginia, including water contamination, economic impacts on current and future businesses, human health effects, the impact to ecosystem services and recreational resources, and effects on aquatic animals and other aspects of the natural environment. Although studies particular to the Virginia site are limited, technical and socioeconomic studies are due out in early December and should provide insight into the impacts specific to this area. A review of economic and environmental analyses and studies on other sites of uranium mining lays the groundwork for evaluating the potential costs of lifting the uranium mining ban in Virginia and also serves as a lens through which to judge the accuracy and comprehensiveness of the Coles Hill studies being undertaken. The following discussion uses domestic and international studies on the effects of uranium mining as well as a cost-benefit analysis of a similar proposed mining site in Virginia from 1984 to provide a preliminary understanding of the economic concerns and considerations around uranium mining.

Cost-Benefit Analysis of Uranium Mining:

Cost-Benefit Analysis of Mining & Milling Uranium at the Swanson Site in Pittsylvania County, Virginia. Knapp, John L, Project Leader and Co-author, Beverly H. Capone, Bruce F. Parsell, William T. Smith, II, James C. Dunstan. Tayloe Murphy Institute, the Colgate Darden Graduate School of Business Administration, University of Virginia. August 1984.

In the 1980's, Virginia was also considering a proposal to lift the ban on uranium mining, and commissioned the aforementioned report for the Virginia Coal and Energy Commission under the direction of its Uranium Task Force. This report examines three major cost categories, including increased state and local government expenditures caused by the project, effects on industry in the area, and environmental degradation. In its final conclusion, this study estimated that benefits to allowing uranium mining far outweighed the costs, however, it has a few serious flaws and assumptions that are evident when viewed under today's drastically different perspective on natural resource economics. Yet, this study is useful to review in that it illustrates important issues to watch for in the new socioeconomic study.

The first problem with this study is that it assumes perfect compliance with all regulations by the mining company and perfect enforcement from the state. The study's conclusion states that "no significant degradation of surface waters, [and groundwater], is expected during normal operations, assuming enforcement of current state and federal regulations."[4] Although it would be nice to believe that regulations will constantly followed and effectively enforced, this idealized state is simply not the case. Also, the emphasis of the study is on "normal operations" of the mine, and does not "attempt to estimate the loss due to accidents."[5] An economic impact assessment cannot be complete without attempting to estimate the costs of an accident, and although the authors of this study may not have had the resources or economic models to attempt to quantify these costs, the new socioeconomic study needs to address costs related to at least the most common accidents surrounding uranium mining.

The most significant flaw of this cost-benefit analysis is the lack of quantifying the impacts to ecosystem services, such as water filtration, food production, recreational/spiritual benefits, and the natural environment as a whole: "Such costs and benefits, usually referred to as intangibles, are an especially severe problem in this study because one important effect of the project, environmental degradation, is largely intangible."[6] This is largely due to the fact that this study was done prior towards the "green economics" movement in which new economic thinking and models were developed in an attempt to put a price tag on these important environmental impacts. It is because this study does not incorporate environmental costs into its analysis that it reaches the conclusion that the benefits outweighing the costs. Although the new paradigm of natural resource economics has not yet developed models for quantifying every single environmental impact, (for example, attempts to quantify existence value, i.e. how much a place or resource is worth to someone just because it exists, is still a hotly debated topic), it is essential that the new socioeconomic study learn from the mistake of this previous cost-benefit analysis. Only with a fuller picture of the true costs and benefits to lifting the uranium mining ban will the General Assembly and the public have the sufficient information necessary to decide their direction going forward.

Manipulation of Financial Benefits:

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[4] Knapp, John L., Beverly H. Capone, Bruce F. Parsell, William T. Smith, James C. Dunstan, "Cost-Benefit Analysis of Uranium Mining & Milling Uranium at the Swanson Site in Pittsylvania County, Virginia," University of Virginia, August 1984. Prepared for the Virginia Coal and Energy Commission under the direction of its Uranium Task Force, xvi.

[5] Knapp, xvi.

[6] Knapp, 10.

New Mexico has a legacy of uranium mining that dates back to the early days of uranium exploration, and serves as an excellent example of the benefits and costs of permitting uranium mining. In *An Economic Evaluation of a Renewed Uranium Mining Boom in New Mexico,* Thomas Michael Power, Professor Emeritus of the Economics Department at the University of Montana, explores the push for renewed uranium mining and milling in a state that has seen the boom and bust of the uranium mining industry many times before. His analysis, although focused on New Mexico, offers valuable insight that can be applied to Virginia's current debate.

A surge in the price of uranium in 2008 sparked interest in restarting the dead uranium mining industry in New Mexico, and economic forecasts from companies predicted billions of dollars in uranium would be extracted. As tantalizing as it sounds that billions of dollars lay just under the surface waiting to be extracted, these large forecasts hide assumptions that inflate the economic benefit. First of all, the forecasts for mining in New Mexico assumed a price for uranium at $90-$100 that would last indefinitely, an assumption that history demonstrates is not true. These prices did not even hold for a year after the forecasts were made, and the current price of uranium hovers around $50. Secondly, these billions are presented as accruing directly to New Mexico workers and citizens. While it is true that there will be some tax revenue increases to local and state governments and new income for some workers, the vast majority of the profit will be absorbed by the company and its stakeholders: "Much of the total value of the uranium would flow out of state to those who put up the capital for the exploration and development of the mines and mills, as profit to the companies doing the mining, to pay for the equipment used in the mining, most of which is not manufactured in New Mexico, and to cover other out-of-state costs."[7] Virginia Uranium may promise millions, but the actual benefit to the local people and economy will be much smaller.

The promise of new revenue streams for local and state governments in the form of taxes is also deceptive because it is often presented as if the government is getting this new revenue for free. This new revenue, however, is not a pure benefit as more workers and businesses require and demand more governmental services. As Power states, "There will be a net fiscal gain to the county governments only if the cost of the additional services is less than the increase in tax revenues."[8]

Economic Instability:

In a depressed economy such as that which is currently plaguing the US, people are more disposed to approve of anything that promises to provide jobs, especially high paying jobs like those found in the metal mining industry. Closer examination of the job prospects promised by uranium mining companies,

[7] Power, Thomas Michael, "An Economic Evaluation of a Renewed Uranium Mining Boom in New Mexico: A report prepared for the New Mexico Environmental Law Center," October, 2008. Available at nmenvirolaw.org, 7-8.
[8] Power, 4.

however, demonstrates that these jobs are not reliable nor assured in the long-term and should not be the basis on which Virginia makes its decision on whether to lift their uranium mining ban.

Uranium is bought and sold in a global commodity market, which is characterized by natural boom and bust cycles. Basic economic theory argues that as the price of a commodity, like uranium, increases, new mines are brought online to take advantage of this higher price. As supply increases, the price of the commodity will go back down, thereby undermining those companies with higher operating costs until they are pushed out of the market. Excess production is absorbed and the price once again stabilizes. The uranium reserves in the United States are of lower quality and have higher extraction costs, (due to stricter health, safety, and environmental regulations), than many of the other reserves around the world. This means that as the price begins to fall again, it may be uneconomical for a US uranium mining company to continue their operations. The temporary or permanent closing of these mines will put people back out of work and can destroy the fabric of communities and disrupt local economies. The last uranium mining boom and bust in New Mexico exemplifies the economic instability of the industry and the jobs it provided: In 1980, at the peak of production, 7,000 workers were employed in New Mexico's uranium mines and mills. By 1986, this number had fallen to 300, and in 1991, it was down to 100. In 2005, only 67 people were employed in uranium mining operations and all of these worked in reclamation of old mining sites.[9] Over the short span of 25 years, all of these uranium mining jobs were lost. Virginia should consider this fact- the uranium mining industry is volatile and the jobs, taxes, and royalties it creates cannot be relied on for long-term economic development planning. Similarly, the uranium mining industry is not sheltered from technological breakthroughs, and advancements in technologies have drastically reduced the number of workers necessary for mining. There is no reason to believe that this trend will cease, thus, many of the jobs promised at the outset may not last even 25 years.

Future Economic Impacts:

Although the concept behind allowing uranium mining would be increased jobs and a needed boost to the economy, it has been demonstrated that these jobs and tax dollars are not permanent. Uranium mining also can discourage growth in other areas of the local economy and can leave the mining communities in a worse position than before the mining began: "When communities become specialized in metal mining, they go through severe cycles of economic expansion followed by economic collapse that severely stresses families and tends to tear the social fabric of communities as workers have to commute out to work or they and their families have to move away. The ongoing decline in labor demand can strand substantial local government infrastructure as well as private commercial infrastructure as the population declines. Mining communities come to be dominated by abandoned businesses and buildings and take on a run-down appearance. The massive damage to the surrounding landscape

[9] Power, 10.

associated with extracting very low grade ores and disposing of the waste also discourages the in-migration of people and businesses not associated with mining. The result is ongoing local economic decline despite the high wages paid to miners and the huge amounts of wealth extracted."[10]

In our new global economy, businesses and people have become much more mobile and thus, the residential location choices have become much more important in determining the location of economic activity, with the result that "economic activity increasingly follows people rather than people following businesses."[11] In Power's research, he has seen that those communities that continued to rely on natural resource extraction have lagged behind others in almost every economic indicator and have had a hard time attracting new residents and businesses. He emphasizes that what has allowed communities to prosper in this new age of mobility is the landscape and climatic features that attract recreationists, retirees, and other new residents, and those communities that recognize and protect their human, cultural, and environmental capital will succeed: "They are now the source of increasingly valuable environmental services, including: clean water and air, cultural and historical preservation, recreational opportunities, wildlife, scenic beauty, biodiversity, and environmental stabilization. Those environmental services provided by protected landscapes make the communities embedded in them attractive places to live, work, and do business."[12] Environmental regulation must be incorporated into development strategy, rather than allowing short-term economic development strategy to undermine and destroy a community's increasingly important social and environmental capital. "The natural, cultural, and environmental and social characteristics of a local area that allow it to attract and hold people are an important part of the area's economic base. If this is not recognized, that part of the economic base may be irreversibly damaged…In that context, those locally specific qualities that make a particular area an attractive place to live, work, and do business are not just of aesthetic interest, they are part of the local area's economic base."[13] In evaluating the decision as to whether to allow uranium mining, Virginia must consider how this would affect its human and natural capital and prospects for future long-term economic vitality.

Economics of Water Contamination:

Uranium mining generates massive amounts of waste; since the uranium is only a small percentage of the rock, almost everything that is mined is left over as tailings, including toxic heavy metals, (arsenic, lead, cadmium, molybdenum, selenium, uranium, nickel), chemicals, and other radioactive elements, (radium, thallium, and polonium). These tailings can pose a threat to groundwater and surface water, and therefore human and environmental health, as evidenced in the many instances of water contamination across the country. Contamination to surface waters occurs from runoff of tailing ponds due to accidents, damn failure,

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[10] Power, 32.
[11] Power, 48.
[12] Power, 53.
[13] Power, 52.

and weather events, as well as through recharge from contaminated aquifers, while contaminants like arsenic can leach through soil and rock to contaminate groundwater aquifers. The process of groundwater contamination most often occurs over long periods of time, facilitated by interaction with water, and can continue long after the mining company has left. The geology of each uranium mining site is different and will determine the amount and movement of contaminants, including uranium: "The mobility of uranium and its leaching to groundwater is dependent on several factors like pH, redox potential, concentration of complexing anions, porosity of the medium, temperature, presence of organic and inorganic compounds, amount of water available for leaching and microbial activity."[14] The geological formations and hydrological pathways in Virginia, as well as the potential for contamination to surface and groundwater drinking water sources, must be seriously considered in the debate over lifting the moratorium on uranium mining.

Another concern particular to Virginia is the possible impacts of water contamination on fish populations located in the Roanoke River Basin downstream from the Coles Hill site. Although each fish species reacts differently, a recent study on selenium concentrations, (an element often found in uranium mining waste), downstream from uranium mining and milling operations demonstrates the major impact these compounds can have on fish populations.[15] Although the selenium concentration in the water might be low, the concentrations in plankton can be high, and thus, selenium can bioaccumulate up the food chain. Selenium poses an interesting paradox in that fish need a certain amount to survive, but too much can be toxic, accumulating in the liver and muscles of the fish and causing skeletal "deformities (lordosis (concave spine), kyphosis (convex spine), scoliosis (lateral curvature of the spine), craniofacial deformities and missing or deformed fins…reduced growth, hemorrhaging of the gill, reduced hematocrit levels with elevated lymphocytes, necrosis of the liver, kidney and ovary, myocarditis, cataracts and juvenile mortality…A high percentage (> 80%) of deformed larvae do not reach the adult stage, and fish populations can be severely impacted due to the rapid decline in recruitment."[16] Selenium is but one potentially toxic element contained in uranium mining waste, and while studies on the impacts of other elements on fish populations is limited, the human toxicity of other elements like arsenic and lead implies that the cumulative impacts from uranium mining on fish could be substantial. Recreational fishing is vital to the residents and tourists in the area downstream from the proposed Coles Hill site, and thus Virginia must ask itself,

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[14] Patra, A. Chakrabarty, C.G. Sumesh, S. Mohapatra, S.K. Sahoo, R.M. Tripathi, V.D. Puranik, "Long-term Leaching of Uranium from Different Waste Matrices," Journal of Environmental Management 92 (2011) 919e925, available online November 16, 2010, 919.

[15] Muscatello, Jorgelina Rosa, "Selenium Accumulation and Effects in Aquatic Organisms Downstream of Uranium Mining and Milling Operations in Northern Saskatchewan," February 2009. Summarized in "Accumulation of selenium in aquatic systems downstream of a uranium mining operation in northern Saskatchewan, Canada," J.R. Muscatello a, A.M. Belknap a, D.M. Janz, Environmental Pollution 156 (2008) 387-393.

[16] Patra, 16-18.

does it want to risk harming its fish populations, recreational resources, and tourism opportunities by allowing uranium mining?

Superfund Classification:

"Some of the environmental costs associated with uranium and other metal mining are nearly permanent in character. Large open pits cannot be realistically reclaimed. Some of the chemical and biological processes triggered when millions of tons of metal ore are brought to the surface and exposed to air and water or where air and water are brought to underground ore deposits cannot be easily stopped."[17] A problem with natural resource extraction is the distribution of costs and benefits, with the benefits largely accruing to a private entity while costs are paid by the public: "Mining has been the source of accidents, disease and premature death among miners for centuries. Uranium mining and processing presents its own particular threats that have to carefully dealt with. The residual environmental and health effects are part of the public costs associated with the uranium industry but which are not included in profit or benefit-cost projections."[18] Sites of past uranium mining and milling throughout the country have become hazardous waste sites and have been designated Superfund sites under the Comprehensive Environmental Response, Compensation, and Liability Act, (CERCLA). Although CERCLA holds private companies responsible for removal and remediation costs of Superfund sites, if these responsible parties are unknown or have gone defunct, the federal government, and thus the taxpayers, are left to bare the clean-up costs.

Billions of dollars have been spent to clean-up the contamination left behind by past uranium mining and milling operations, and these costs are projected to continue into the foreseeable future as more sites are discovered and the Department of Energy continues to engage in long-term monitoring: "Up through 1999 the federal government had spent about $1.5 billion to reclaim 24 'inactive' or abandoned uranium mills and tailings that were the legacy of the nation's nuclear weapons program through 1970. As of 2003, that total topped $2 billion. In addition, the U.S. Department of Energy expects to spend nearly $100 million in long-term monitoring and maintenance costs at these sites until 2070 and $50 million in groundwater remediation costs at only three of the 24 sites: Shiprock, New Mexico, and Tuba City and Monument Valley Arizona."[19]

The Navajo Nation, whose territorial lands cover three states in the Four Corners region, has a legacy of uranium mining contamination that continues more than two decades after the mines have closed, and includes over 500 abandoned uranium mines, homes, and drinking water sources with elevated levels of radiation.[20] Working with the EPA under their Superfund authority since 1994, the Navajo Nation has spent over $23 million to correct safety hazards and perform reclamation on nearly one thousand abandoned uranium mines, with

[17] Power, 55.
[18] Power, 31.
[19] Power, 15.
[20] United States Environmental Protection Agency, "Addressing Uranium Contamination in the Navajo Nation," http://www.epa.gov/region9/superfund/navajo-nation/.

officials estimating that "at least one-half billion dollars will be needed just to initiate full reclamation and environmental restoration" at the remaining 500 abandoned uranium mines.[21]

Colorado, with its history of uranium mining, currently has 15 Uranium Mill Tailings Remedial Action sites, eight of which are former uranium mines and seven that are permanent disposal sites for mill tailings, now under the long-term monitoring jurisdiction of the DOE. Lincoln Park, a public park located near the site of a uranium ore processing mill, was designated a Superfund site in 1984 following the discovery of contamination of soil and groundwater wells with molybdenum, uranium, radium, radon gas, polonium, selenium, and sulfate. Although for the majority the groundwater is not used as drinking water, it is used for irrigation, and the contaminants, like molybdenum, can be toxic to cud-chewing animals. Over the span of 6 years, 9,000 cubic yards of contaminated tailings, soil, and sediment had to be excavated from 1.25 miles of Sand Creek, a local waterway.[22] The contamination at the Lincoln Park Superfund site is small compared to the Uravan site, another one of Colorado's uranium legacies. The Uravan site began as a radium recovery plant, (radium being a daughter product of uranium), and was later operated as a uranium and vanadium processing facility. The air, soil, and groundwater were contaminated around the facility, including the nearby San Miguel River. The clean-up process was extensive, requiring the capping and revegetating of nearly 10 million cubic yards of radioactive tailings, pumping and treating contaminated groundwater, securing 12 million yards of tailings waste along the San Miguel River, excavating and disposing of contaminated soil in a secure area, and dismantling and cleaning up the town of Uravan.

Clean-up procedures at many uranium mining Superfund sites have yet to begin as issues from contamination can take years to become apparent and determining and negotiating with responsible parties and developing remediation plans can be a long process. For example, the Midnite Mine, located in Washington within the reservation of the Spokane Tribe of Indians, is the site of a uranium mine that operated from 1955-1981. Concerns over elevated levels of radioactivity and acid mine drainage of heavy metals into the groundwater, as well as contamination of nearby Blue Creek, caused the site to be classified as a Superfund site in 2000, almost 20 years after the mine had stopped operations. After years of litigation, a deal was struck in September 2011 between the federal government and Newmont Mining Co., the parent company of the mine, regarding distribution of clean-up costs. The deal includes a $42 million contribution from the US Department of Interior while the company covers $151 million and any additional costs above the estimated cost of remediation, which stands at $193 million. The price tag for remediation of this site is enormous, but these costs to the government and the mining company are not the only ones.

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[21] Power, 29-30.

[22] United States Environmental Protection Agency, "Superfund Program, Lincoln Park," http://www.epa.gov/region8/superfund/co/lincolnpark/index.html.

The Agency for Toxic Substances and Disease Registry has advised that people limit activities in the area, including usage of the water for drinking, ceremonies, or eating any plants or roots from the area or fish from Blue Creek, which has a direct impact on the Spokane Tribe of Indians' ability to use their land for activities like fishing or traditional ceremonies- a cost to them that is not included in the $193 million remediation estimate.

In addition to contamination clean-up costs, the federal government has also had to compensate uranium mine workers and their family for the "diseases and deaths associated with their exposure to radiation during employment in uranium mines and mills and in hauling uranium ore" to the tune of almost $625 million. These clean-up and health costs are staggering, and represent only the costs borne by the public as a whole, not including private costs to individuals and communities that have been impacted by uranium mining activities.

As Virginia debates whether to lift its current moratorium on uranium mining, it must seriously consider whether the uncertain benefits from a volatile industry like uranium are worth the costs that come with it: the risk of contamination requiring millions of dollars in clean-up, the potential for human health and irreversible environmental impacts, and the possibility of destroying its human, natural, and cultural resources that are the key to long-term economic success in our new mobile, global economy.

References

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II. Health Impacts (Ted Ririe)

1) What are the risks and effects of acid and alkaline leaching?

Acid leaching of uranium ore can result in the extraction of "many major and minor elements, for example, Fe [iron] and Mn [manganese]." These elements can then enter the environment by seeping into the ground water. Plants may then uptake these contaminants (Dreesen, D. R.; Williams, J. M.; Marple, M. L.; Gladney, E. S.; Perrin, D. R. *Environ. Sci. Technol.* **1982** 16, 702-09). This may cause potentially harmful contaminants to accumulate in the food chain.

2) What are the health risks to population groups and where are those populations located in relation to potential mining sites?

Populations located near uranium mining and milling operations can be exposed daily to low levels of radioactivity (Stephens, C.; Ahern, M. "Worker and Community Health Impacts Related to Mining Operations Internationally: A Rapid Review of the Literature" Mining, Minerals and Sustainable Development, 2001). One group of researchers has reported negative health impacts on populations located near uranium mining operations (*see* Au, W. W.; Lane, R. G.; Legator, M. S.; Whorton, E. B.; Wilkinson, G. S.; Gabelhart, G. J. *Environ. Health Perpect.* **1995** 103, 466-70; *and* Au, W. W.; McConnell, M. A.; Wilkinson, G. S.; Ramanujam, V. M. S.; Alcock, N. *Mutat. Res.* **1998** 405, 237-45). Other researchers, however, show weak or no correlation between this exposure and negative health outcomes (*see* Boice, J. D.; Mumma, M.; Schweitzer, S.; Blot, W. J. *J. Radiol. Prot.* **2003** 23, 247-62; *and* Boice, J. D.; Mumma, M. T.; Blot, W. J. *Radiat. Res.*, **2007** 167, 711-26). US EPA, however, criticized both studies in Appendix IV to Technical Report on Technologically Enhanced and Naturally Occurring Materials, p.8, stating that these studies share "problems of limited size and control for confounding factors, such as lack of smoking data, specific exposure data, and population migration. Thus, the results of the studies are uninformative about the potential risks from uranium mills." (http://www.epa.gov/radiation/docs/tenorm/402-r-08-005-volii/402-r-08-005-v2-appiv.pdf)

Uranium mining and milling presents a possible contamination threat to food and water supplies. One study indicates that potatoes can take up a significant amount of radium (Ra). Consequently, the authors warn that "in regions of old uranium mines, particular attention should be paid to the presence of enhanced Ra [radium] concentrations in agricultural soils and in irrigation waters" (Carvalho, F. P.; Oliveira, J. M.; Neves, M. O.; Abreu, M. M.; Vicente, E. M. *Geochem.-Explor. Env. A.* **2009** 9, 275-78).

3) What are the potential health risks of uranium and other contaminants (both radiological and non-radiological) that might be released into the environment due to uranium mining and milling operations?

Daughter products of uranium present health concerns. Radium-226 (^{226}Ra), an isotope of radium, is the daughter product of highest concern, because it is highly radiotoxic and it readily accumulates in bones. Also, gaseous radon-222 (^{222}Rn) can be released into the atmosphere and is a “critical pathway for human exposure to radiation” from uranium mining tailings (Landa, E. R.; Gray, J. R. *Environ. Geol.* **1995** 26, 19-31).

The health risk of uranium mining is a “complex” problem. For example, it took 50 years to identify “the nature of risks that men experienced in the mines in the 1940s.” One of the most significant health risks to uranium miners is lung cancer. This risk is due to exposure to “dusts and through released radon.” (Stephens, C.; Ahern, M. “Worker and Community Health Impacts Related to Mining Operations Internationally: A Rapid Review of the Literature” Mining, Minerals and Sustainable Development, 2001). Radon daughters have been revealed to be potent carcinogens (Roscoe, R. J.; Steenland, K.; Halperin, W. E.; Beaumont, J. J.; Waxweiler, R. J. *JAMA* **1989** 262, 629-33). Other research has indicated that uranium miners “are at an increased risk to acquire various degrees of genetic damage.” This type of damage may be associated with increased risks of cancer. (Stephens, C.; Ahern, M. “Worker and Community Health Impacts Related to Mining Operations Internationally: A Rapid Review of the Literature” Mining, Minerals and Sustainable Development, 2001). Occupational exposure to uranium may also negatively affect kidney health (Thun, M. J.; Baker, D. B.; Steenland, K.; Smith, A. B.; Halperin, W.; Berl, T. *Scand. J. Work Environ. Health* **1985** 11, 83-90).

The concentration of uranium in ore is often low, requiring the excavation of a large amount of ore to obtain uranium. Thus, uranium mining and milling operations are a potential source not only of uranium contamination, but of magnesium, manganese, iron, cobalt, nickel, copper, zinc, arsenic, selenium, molybdenum, cadmium, sulfates and ammonium, all of which are potentially toxic (Mkandawire, M.; Dudel, E. G. *Sci. Total Environ.* **2005** 336, 81-89; Muscatello, J. R.; Belknap, A. M.; Janz, D. M. *Environ. Pollut.* **2008** 156, 387-93; *and* Noller, B. N. *Environ. Monit. Assess.* **1991** 19, 383-400). One report provides indirect evidence “that arsenic contamination exists in abandoned uranium mine sites” and that “arsenic may pose more risk than uranium” (Mkandawire, M.; Dudel, E. G. *Sci. Total Environ.* **2005** 336, 81-89). Selenium, if released into the aquatic environment, can accumulate in the food chain. While selenium is a dietary requirement, above certain levels it “can cause deleterious effects.” For example, studies in fish show impaired reproduction due to increased selenium exposure (Muscatello, J. R.; Belknap, A. M.; Janz, D. M. *Environ. Pollut.* **2008** 156, 387-93).

4) What are the potential risks of radioactivity at low-levels long-term and higher levels?

Studies of uranium miners indicate that "prolonged exposure at low levels of radon appears to be more hazardous than shorter exposures to higher levels" (Stephens, C.; Ahern, M. "Worker and Community Health Impacts Related to Mining Operations Internationally: A Rapid Review of the Literature" Mining, Minerals and Sustainable Development, 2001).

5) What are the potential health issues associated with different technologies that could be used? Will there be radon?

The Virginia Uranium website indicates that the Coles Hill site will consist of an underground mine (*see* http://www.virginiauranium.com/faqs.php). Radon, which is a carcinogen (see question 3), is found in underground uranium mines (Stephens, C.; Ahern, M. "Worker and Community Health Impacts Related to Mining Operations Internationally: A Rapid Review of the Literature" Mining, Minerals and Sustainable Development, 2001). The potential risks of occupational exposure to uranium and radon are also described above in question 3.

6) Additional findings that may be of interest:

a. Lichen-caribou-human is a critical food chain in subarctic regions. Currently, several uranium mines are operating in one such region in northeastern Saskatchewan, Canada. Researchers analyzed radionuclide levels in caribou from this area and found that "^{210}Po [polonium-210], ^{137}Cs [cesium-137] and ^{40}K [potassium-40] were present in edible soft tissues" and concluded that "human consumption of these tissues enhances the transfer of these radionuclides through the food chain" (Thomas, P. A.; Gates, T. E. *Environ. Health Perspect.* **1999** 107, 527-37).

b. In addition to uranium's radiotoxic effects, it is also chemically toxic. Studies have shown that "uranium is a developmental toxicant when given orally or subcutaneously . . . to mice" (Domingo, J. L. *Reprod. Toxicol.* **2001** 15, 603-09).

Uranium mining takes place in Australia's Alligator Rivers Region. This is a tropical region with pronounced wet and dry seasons receiving 1,500 mm (59 inches) of rain a year. In their paper, van Dam *et. al* discuss "the major components of a research and monitoring program designed to assess potential and actual effects on ecosystem and human health arising from surface water contamination." This program is "a four-tiered approach including the derivation of local water quality guideline trigger values, direct toxicity assessment of mine waters prior to their release, creekside or in situ monitoring for early warning of adverse effects during mine water release, and longer-term monitoring of macroinvertebrate and fish communities" (van Dam, R. A.; Humphrey, C. L.; Martin, P. *Toxicology* **2002** 181-82, 505-15).